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PROVISIONAL SPECIFICATION

Invention Title: Scanning Device and Method of Scanning an Optical Beam Over a Surface

The invention is described in the following statement:

Title: Scanning Device and Method of Scanning an Optical Beam Over a Surface

Field of the Invention

The present invention relates to an optical scanning device and a method of scanning an optical beam over a surface. The applications of the present invention include, for example, surgical and medical applications, such as operations for correcting refractive errors of the eye by photorefractive keratectomy (PRK) or laser in-situ keratomileusis (LASIK). Other material processing examples of applications of the present invention include photolithography in microchip manufacture and glass marking.

Background of the Invention

The specification refers to and describes content of US patents 5,520,679, 6,339,278, 6,339,470 and 6,342,751. However, neither the disclosures in those US patents nor the description contained herein of content of those US patents is to be taken as forming part of the common general knowledge solely by virtue of the inclusion herein of the reference to and description of content of those US patents. Furthermore, this specification describes aspects of prior art optical scanning systems. However, neither such aspects of prior art optical scanning systems nor the description contained herein of such aspects of prior art optical scanning systems is to be taken as forming part of the common general knowledge solely by virtue of the inclusion herein of reference to and description of such aspects of prior art optical scanning systems.

A wide range of lasers are suitable for the above applications, including: excimer lasers, Nd:YAG, Nd:YLF, Er:YAG, Nd:KGW, Carbon Monoxide, and Carbon Dioxide lasers. The wavelengths produced by these lasers range from deep in the ultra-violet (UV) to long infra-red (IR) wavelengths.

A feature that is often common among the use of these lasers for material processing is the need to move the laser beam relative to the material surface being processed. When the material is not deliberately being moved and the laser beam is being directed to carry out the processing, the movement of the

laser beam is often performed by galvanometer or motor driven mirrors and lenses.

In the field of treating refractive errors by laser ablation, J. T. Lin (US patent 5,520,679) proposed using galvanometer scanners to control a low energy laser beam into an overlapping pattern of adjacent pulses to produce the desired change in the corneal surface. US patent 5,520,679 states that this allows a smaller, lower cost laser to be used for this procedure. US patent 5,520,679 also states other advantages, including a reduced need for a homogenous beam and better flexibility in design of the treatment.

Galvanometer scanning excimer lasers are currently one of the most common means for correcting refractive errors using the LASIK surgical procedure.

Although galvanometer scanners have been very successful in scanning lasers for reshaping corneal tissue and a large range of other applications, they do have some disadvantages. They have a trade-off between the size and weight of the mirror being tilted and the speed by which the galvanometer can adjust its position. Sometimes this results in mirrors that are not large enough for the optical system or using mirrors that are too thin to maintain their required flatness during the scanning process. Galvanometer scanners also have limited accuracy when the desired scan angle is small (less than 3 degrees).

The galvanometer scanners used in refractive lasers generally work well at the pulse repetition rates currently used, i.e. 200Hz or below. However, this assumes that the eye is not moving. Tracking the eye has now become an important part of producing good results for refractive surgery. Between each pulse the position of the eye is measured and then the scanner position adjusted to compensate for any eye movements before the eye moves again. This means that the scanner must be capable of moving much faster than when the laser was operating without an eye tracker. These faster response requirements from the scanner go beyond the response capabilities of galvanometers. This becomes even more of a problem when the demands of customised surgery require smaller spot sizes to ablate with higher precision and subsequently much higher pulse repetition rates. Galvanometric scanners would not have adequate response for

such a laser system.

A problem that sometimes occurs in galvanometric scanners if the eye moves slightly up and down, getting closer or further away from the laser, is that each pulse may not hit the eye in the correct position. Because of the scan angle, if the eye is too close to the laser system then the pulses over-lap more than intended and the total area exposed to the laser is less than intended. If the eye is too far from the laser the opposite occurs. In either case, the result of the surgery is degraded.

An alternative drive mechanism to a galvanometer drive mechanism is a piezoelectric drive.

Piezoelectric drives have the advantages of having potentially infinite precision and are capable of generating extremely high forces, so could drive a large mirror very fast. However, piezoelectric drives also have a number of significant disadvantages, and although they have been used to scan laser beams, they have not been generally accepted for this type of application because of these disadvantages.

The main disadvantage of piezoelectric drive systems is their very limited range of movement. They are therefore not considered to be a potential means of scanning in applications currently performed by galvanometer scanners. One method that has been used to amplify the range of piezoelectric scanning is to have the piezoelectric crystals push or pull on the end of a metal plate. The metal plate bends and deflects a mirror further than the same piezo would move the mirror if applied behind the edge of the mirror. A device based on this technique is described by Takeuchi et al in US patent 6,342,751. However, this type of technique creates a non-linear beam deflection and loses much of the potential accuracy of a piezoelectric drive mechanism, and still has a much smaller range of scanning than galvanometer scanners. These types of techniques also suffer from reduced response time, stiffness and have a significantly smaller force/load capability.

The second significant problem with piezoelectric drive systems, or actuators, is

that they have significant hysteresis. This is normally in the order of 10% to 15% of the range of the movement. This hysteresis is another key reason why piezoelectric driven scanners are currently not used in applications requiring fast complex scan pattens, such as laser systems for refractive surgery. This hysteresis can be corrected by operating the piezoelectric system in a closed loop fashion. This requires a sensor to measure the movement of the system and then a controller that adjusts the voltage to the piezoelectric actuator so that it moves to the desired position. The problem with this is that it significantly reduces the response of the system, and its accuracy is reduced to the accuracy of the sensor. In an application in which tolerances are critical, such as refractive surgery, the hysteresis induced error can be so large that the piezoelectric signal and position sensor signal cannot be compared to check the system is operating correctly. So to achieve a redundant check of scanning performance a second position sensor would need to be used.

Papademetriou et al in US patent 6,339,470 describes means for scanning lasers across optical fibres. This US patent also describes use of a piezoelectric stack to adjust the angle of a mirror. However, this description complains of the lack of range of such a scanning mechanism as special effort is required to scan the laser across the entrance of a single optical fibre. The main scanning mechanism used in the device described in this US patent relies on acousto-optic deflection of the laser beam, where that scan range must cover more than one optic fibre (which is smaller than the range across an eye). Acousto-optic scanners are relatively complex, have high optical losses and are not suitable for many of the wavelengths used for material processing applications.

The background description in US patent 6,339,278, (Shinohara et al) describes conventional inclination optical scanners and lists galvanometers, stepper motors and other mechanisms as examples but not piezoelectric mechanisms. However, the invention described in this US patent does use a piezoelectric device, but it is used as a mechanical oscillator to drive an ultrasonic motor that deflects the laser beam.

Disclosure of the Invention

In accordance with one aspect of the present invention, there is provided an optical scanning device comprising:

a platform,

a mirror provided on said platform to reflect an optical beam incident on said mirror,

a pivot about which said platform is able to pivot,

at least first piezoelectric actuator means to pivot said platform about said pivot in a first direction,

at least first resilient means to bias said platform about said pivot in a second direction opposed to said first direction,

wherein said first piezoelectric actuator means acts on said platform at a location in proximity to said pivot to pivot said platform such that the angle at which said beam is reflected by said mirror is altered to thereby scan the reflected beam in a first plane over a surface.

In an alternative form, the optical scanning device further comprises:

second piezoelectric actuator means to pivot said platform about said pivot in a third direction,

second resilient means to bias said platform about said pivot in a fourth direction opposed to said third direction, and

wherein said second piezoelectric actuator means acts on said platform at a location in proximity to said pivot to pivot said platform such that the angle at which said beam is reflected by said mirror is altered to thereby scan the reflected beam in a second plane, over the surface, said first plane and said second plane being substantially mutually orthogonal.

Preferably, said first piezoelectric actuator means acts on said platform to push

said platform and said first resilient means is compressively or expandably resilient.

Alternatively, said first piezoelectric actuator means acts on said platform to pull said platform and said first resilient means is compressively or expandibly resilient.

Preferably, said second piezoelectric actuator means acts on said platform to push said platform and said second resilient means is compressively or expandably resilient.

Alternatively, said second piezoelectric actuator means acts on said platform to pull said platform and said second resilient means is compressively or expandably resilient.

The optical beam incident on said mirror provided on said platform may be a laser beam.

In accordance with a second aspect of the present invention there is provided a refractive eye surgery laser apparatus comprising;

a laser to emit an optical beam,

a first optical scanning device, and

a second optical scanning device,

said first optical scanning device and said second optical scanning device each comprising

a platform,

a mirror provided on said platform to reflect a said optical beam incident on said mirror,

a pivot about which said platform is able to pivot,

piezoelectric actuator means to pivot said platform about said pivot in one direction, said piezoelectric actuator means acting on said platform at a

location in proximity to said pivot, and

resilient means to bias said platform about said pivot in a direction opposed to said one direction,

wherein said piezoelectric actuator means of said first optical scanning device acts on said platform at a location in proximity to said pivot to pivot said platform of first optical scanning device such that the angle at which said beam is reflected by said mirror of said first optical scanning device is altered to thereby scan the reflected beam in a first plane and said second optical scanning device is arranged such that said mirror of said second optical scanning device receives said beam reflected by said mirror of said first optical scanning device and said piezoelectric actuator means of said second optical scanning device acts on said platform at a location in proximity to said pivot to pivot said platform of said second optical scanning device such that the angle at which said beam is reflected by said mirror of said second optical scanning device is altered to thereby scan the reflected beam in a second plane, said first and second planes being substantially mutually orthogonal, to thereby scan the reflected beam over the eye of a patient to perform refractive surgery thereon by the reflected beam and the path of the reflected beam from said second optical scanning device to the eye of the patient is substantially one metre or more in length.

Preferably, a second mirror is provided to reflect the reflected beam reflected by said mirror of said second optical scanning device.

More preferably, a third mirror is provided to receive the reflected beam from said second mirror and said third mirror reflects said beam to the eye of the patient.

In accordance with a third aspect of the present invention there is provided a refractive eye surgery laser apparatus comprising:

a laser to emit an optical beam, and

an optical scanning device comprising

a platform,

a mirror provided on said platform to reflect a said optical beam incident on said mirror,

a pivot about which said platform is able to pivot,

first piezoelectric actuator means to act on said platform at a location in proximity to said pivot to pivot said platform about said pivot in a first direction,

first resilient means to bias said platform about said pivot in a second direction opposed to said first direction,

second piezoelectric actuator means to pivot said platform about said pivot in a third direction,

second resilient means to bias said platform about said pivot in a fourth direction opposed to said third direction,

wherein said first piezoelectric actuator means pivots said platform such that the angle at which said beam is reflected by said mirror is altered to alter the path of the reflected beam to thereby scan the reflected beam in a first plane and said second piezoelectric actuator means pivots said platform such that angle at which said beam is reflected by said mirror is altered to alter the path of the reflected beam to thereby scan the reflected beam in a second plane, said first plane and said second plane being substantially mutually orthogonal to thereby scan the reflected beam over the eye of a patient to perform refractive surgery thereon by the reflected beam and the optical path of the reflected beam from said optical scanning device to the eye of the patient being substantially one metre or more in length.

Preferably, a second mirror is provided to reflect the reflected beam reflected by said mirror.

More preferably, a third mirror is provided to receive the reflected beam from said second mirror and said third mirror reflects said beam to the eye of the patient.

In accordance with a fourth aspect of the present invention there is provided a

method of scanning an optical beam in at least a first plane, over a surface using an optical scanning device as hereinbefore described comprising

determining a required location for an optical beam to be incident on a surface,

determining whether the required location requires a positive or negative change to the voltage applied to said piezoelectric actuator means to pivot said platform to a required position corresponding to the said required location,

comparing the existing position of said platform and voltage applied to said piezoelectric actuator means with the required position of said platform,

calculating the required voltage to be applied to said piezoelectric actuator means corresponding to the required position of said platform,

applying the said required voltage to said piezoelectric actuator means to move the platform to said required position such that the optical beam is incident at the said required location.

Preferably, said required position of said platform and corresponding required voltage to be applied to said piezoelectric actuator means are recorded for use in determining the voltage to be applied to said piezoelectric actuator means for the next location at which said optical beam is to be incident on said surface

Brief Description of the Drawings

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a view of a first embodiment of an optical scanning device in accordance with an aspect of the present invention;

Figure 2 are plots of the relationship between the position of the platform of the scanning device shown in Figure 1 versus the corresponding voltage to be applied to the piezoelectric actuator of the scanning device shown in Figure 1

Figure 3 is a view of an arrangement of two optical scanning devices, of the type shown in Figure 1, arranged so as to scan an optical beam in two dimensions or

planes;

Figure 4 is a view of a second embodiment of an optical scanning device in accordance with an aspect of the present invention;

Figure 5 is a schematic illustration of a refractive surgery laser apparatus in accordance with another aspect of the present invention.

Best Mode of Carrying out the Invention

In Figure 1, there is shown an optical scanning device 1 that is able to reflect an incident optical beam I so that the reflected optical beam R can be directed to a surface S such that the reflected optical beam R is scanned over the surface S.

The optical scanning device 1 comprises a platform 2, a mirror 4 having a reflective surface 6, a pivot 8 about which the platform 2 is able to pivot, a piezoelectric stack actuator 10 to pivot the platform 2 about the pivot 8 in a first direction, and a resilient spring 12 to bias the platform 2 about the pivot 8 in a second direction that is opposed to the first direction. The pivot 8 is a pivot shaft.

Voltage can be applied to the piezoelectric stack actuator 10 to expand the piezoelectric stack actuator 10. The piezoelectric stack actuator 10 acts on the platform 2 at a location in proximity to the pivot 8. For example, the piezoelectric stack actuator 10 may act on the platform 2 at a location that is spaced substantially 5 to 15mm from the pivot 8. Expansion of the piezoelectric stack actuator 10 causes the platform 2 to pivot about the pivot 8 in the direction shown by arrow A in Figure 1. The spring 12 acts to bias the platform 2 about the pivot 8 in a second direction, shown by arrow B in Figure 1, that is opposed to the first direction (shown by arrow A). Thus, when a voltage is applied to the piezoelectric stack actuator 10, the piezoelectric stack actuator 10 acts against the spring 12 to pivot the platform 2 in the direction shown by arrow A. Once the voltage is removed from the piezoelectric stack actuator 10, the spring 12 returns the platform 2 to its original position.

The spring 12 may be arranged, as required, to bias the platform 2 in a direction opposed to the direction in which the platform 2 is pivoted by the piezoelectric

stack actuator 10. The spring 12 may be compressively or expandibly resilient as required.

The optical scanning device 1 is able to scan the reflected optical beam R in a first dimension or plane.

For given scan patterns of an optical beam, such as a laser beam, over a surface S, a relationship exists between the voltage applied to the piezoelectric stack actuator 10 and the pivot position of the platform 2 (also referred to as the "scanning device position" or "scanner position") and consequently the target, or incident, location of the reflected optical beam R on the surface S.

The scan patterns have steps between each location that vary in distance and direction in a quasi random fashion. The steps in the scan patterns equate to different incident locations of the beam R on the surface S and correspondingly different scanning device positions. The variation of the steps in the scan pattern in a quasi random fashion is achieved by corresponding quasi random changes in the voltage applied to the piezoelectric stack actuator 10. This is in contrast to a regular scan pattern which uses systematic, i.e. non random changes, in the applied voltage. The reason that a quasi random variation is used is that a different shape is being sculpted each time the scanning device 1 is used and there is a need to move the laser beam across the surface being processed so that consecutive laser beam pulses do not overlap and thermal loading is spread across both the surface and time. There may also be a need to adjust the scan pattern to compensate for movements of the surface being treated that may occur.

However, for a given voltage applied to the piezoelectric stack actuator 10, the position of the platform 2 may vary by 10% of the full range of movement due to hystersis occurring in the piezoelectric stack actuator 10, the resultant locations are nevertheless reproducible. The positions of the platform 2 corresponding to these locations can also be determined and are reproducible. It is thus possible to determine a relationship between the scan pattern signal, i.e. the voltage applied to the piezoelectric stack actuator 10, and the position of the platform 2 such that the voltage applied to the piezoelectric stack actuator 10 can be adjusted in

advance. In this way, the piezoelectric stack actuator 10 can pivot the platform 2 and thereby the mirror 4 into the correct required position so that the beam R is incident on the surface S at the required incident location.

The relationships between the applied voltage and scanning device position can be determined experimentally for given scan patterns and plotted to produce curves representing the relationships. An example of relationships for scanning device position and voltage applied to the piezoelectric stack actuator 10 is shown in Figure 2.

The platform 2 of the scanning device 1 may thus be pivoted to the correct position without the need to rely on closed loop feedback. However, the scanning device 1, when used in a closed loop fashion, would also increase the response speed of the scanning device 1 and allow a position sensor to operate as a redundant check of the position of the scanning device 1.

The scanning device 1 may thus be operated as hereinbelow described.

As stated previously herein, for a given current position of the scanning device 1 and a given current voltage applied to the piezoelectric stack actuator 10, the scanning device 1 will follow a predictable path for changes in the applied voltage to the piezoelectric stack actuator 10. These predictable paths are represented by the curves in Figure 2. The path differs for increases or decreases in the voltage applied to the piezoelectric stack actuator 10 and also depends on the type of piezoelectric device used in the piezoelectric stack actuator 10. These paths are first determined experimentally for a scanning device 1 employing a piezoelectric stack actuator 10 having a particular piezoelectric device.

When it is required to move the incident location of the beam R on the surface S to a new required location, it is determined whether the new required location requires a positive or negative change to the voltage applied to the piezoelectric stack actuator 10 to pivot the platform 2 about the pivot point 8 to a new required position, corresponding to the new required location of the beam R, so that the beam R will strike the surface S at the new required location.

The correct path curve is determined that contains the current scanning device

position and applied voltage at the current position of the scanning device. This determination can be made from the relationship between the scanning device position and the applied voltage, which has been previously determined, i.e. as shown in the plot of scanning device position verses applied voltage, as shown in Figure 2.

This is then used to calculate the new applied voltage required for the new required position of the scanning device. The current scanning device position and the required applied voltage is then recorded for use in determining the voltage to apply to the piezoelectric stack actuator device 10 for the next required position of the scanning device.

If the current position of the scanning device in unknown, e.g. when the scanning device 1 is first switched on, then a voltage of zero can be applied which will produce a fixed position that does not depend on the previous voltage. Effectively, this resets the scanner position to a initial condition.

As previously hereinbefore described, the scanning device 1 is able to scan the beam R in a single dimension or plane. In Figure 3 there is shown a scanning device 1a and scanning device 1b. The scanning devices 1a and 1b are of the same type as the scanning device 1 as previously hereinbefore described with reference to Figure 1.

The scanning devices 1a and 1b are arranged such that the beam R reflected by the first scanning device 1a can be scanned in a first dimension or plane and is incident upon the mirror 4b of the second optical scanning device 1b. The second optical scanning device 1b is able to reflect the beam R and scan it in a second dimension or plane. The first dimension or plane is substantially orthogonal to the second dimension or plane. In this way, the arrangement of the scanning devices 1a and 1b shown in Figure 3 can scan the reflected beam in two dimensions or planes that are substantially orthogonal to each other. This enables the reflected beam to be scanned in two dimensions over the surface S.

The piezoelectric stack actuator 10b (obscured in Figure. 3) of the second scanning device 1b pivots the platform 2b about the pivot 8b (obscured in Figure

3) of the second scanning device 1b in a direction that is substantially orthogonal to the direction in which the piezoelectric stack actuator 10a pivots the platform 2a of the first scanning device 1a. Similarly, the spring 12b biases the platform 2b about the pivot 8b of the second scanning device 1b in a direction that is substantially orthogonal to the direction in which the spring 12a biases the platform 2a about the pivot 8a of the first scanning device 1a.

In the arrangement shown in Figure 3, the first scanning device 1a receives an incident beam I from a laser 22 and is able to scan the reflected beam R in the plane of the drawing sheet depicting Figure 3. This reflected beam R is incident upon the mirror 4b of the second scanning device 1b. The beam R is reflected by the mirror 4b of the second scanning device 1b and can be scanned by the second scanning device 1b in a plane that is substantially orthogonal to the plane of the drawing sheet depicting Figure 3, i.e. the beam R is reflected by the mirror 4b, in a plane, out of the drawing sheet depicting Figure 3.

The description of the relationship between the voltage applied to the piezoelectric stack actuator 10 and the pivot position of the platform 2 and the previous description herein of the operation of the scanning device 1 with reference to Figures 1 and 2 applies to the scanning devices 1a and 1b shown in Figure 3. The scanning devices 1a and 1b operate together to enable the reflected beam R to be scanned in two dimensions or planes.

In Figure 4 there is shown a second embodiment of an optical scanning device 11. The optical scanning device 11 is similar to the optical scanning device 1, except that the optical scanning device 11 is provided with a pair of piezoelectric stack actuators 10aa and 10bb and a pair of resilient springs 12aa and 12bb and the pivot 8ab allows the platform 2 to pivot in at least two directions that are substantially mutually orthogonal thereto.

The pivot 8ab may be provided near a corner of the platform 2. The pivot 8ab may be provided as a ball that allows the platform 2 to swivel in any direction.

The piezoelectric stack actuators 10aa and 10bb and the springs 12aa and 12bb may be provided in proximity to the pivot 8ab. The piezoelectric stack actuators

10aa and 10bb may be provided such that they act on the platform 2 in proximity to the pivot 8ab, for example, at a location spaced substantially 5 to 15mm from the pivot 8ab.

The scanning device 11 permits the platform 2 to pivot in two substantially orthogonal dimensions or planes. Thus, the scanning device 11 provides an alternative to using two scanning devices 1a and 1b, as shown in Figure 3, to achieve scanning of the beam R in two substantially orthogonal dimensions or planes.

The piezoelectric stack actuator 10aa causes the platform 2 to pivot about the pivot 8ab in a first direction shown by arrow C in Figure 4. The spring 12aa acts to bias the platform 2 about the pivot 8ab in a second direction, shown by arrow F in Figure 4, that is opposed to the direction shown by arrow C. Similarly, the piezoelectric stack actuator 10bb causes the platform 2 to pivot about the pivot 8ab in the direction shown by arrow D in Figure 1. The spring 12bb acts to bias the platform 2 about the pivot 8ab in a direction, shown by arrow G in Figure 1, that is opposed to the direction indicated by arrow D. The directions in which the piezoelectric stack actuators 10aa and 10bb pivot the platform 2 are mutually orthogonal to each other. The piezoelectric stack actuator 10aa and spring 12aa enable a reflected beam R to be scanned in a first dimension or plane and the piezoelectric stack actuator 10bb and spring 12bb enable the reflected beam R to be scanned in a second dimension or plane. The first dimension or plane is substantially orthogonal to the second dimension or plane.

In this way, the reflected beam R can be scanned in two dimensions or planes over a surface S.

The description of the relationship between the voltage applied to the piezoelectric stack actuator 10 and the pivot position of the platform 2 and the operation of the scanning device 1, previously hereinbefore described with reference to Figures 1 and 2, also applies to the operation of the scanning device 11.

In Figure 5 there is shown a refractive surgery laser apparatus 20.

The refractive surgery laser apparatus 20 comprises an optical scanning unit

("OSU"), a laser 22 and first and second mirrors 24 and 26, respectively.

The OSU may be either an arrangement of two scanning devices 1a and 1b, as shown in Figure 3, or a scanning device 11 as shown in Figure 4. In this way, the OSU is able to reflect and incident beam I so that the reflected beam R can be scanned in two dimensions or planes.

The laser 22 emits the laser beam I which is directed to the mirrors 4aa and 4bb, or mirror 4, of the OSU. The mirrors 4aa and 4bb, or mirror 4, reflects the incident beam I as reflected beam R.

The reflected beam R is reflected by the mirrors 4aa and 4bb, or mirror 4, of the OSU to a mirror 24. The mirror 24, in turn, reflects the beam R to a second mirror 26. The mirror 26 reflects the beam R and directs it to the surface to be treated, in this case being the eye E of a patient P.

The OSU is operated, in the manner hereinbefore described with reference to the scanning device 1 and Figs 1 and 2, to scan the beam R over the surface of the eye E in the required scan pattern to carry out refractive surgery on the eye E using the laser beam R.

The pivotal movement of the platforms 2a and 2b, or the platform 2, of the OSU about the pivots 8a and 8b, or the pivot 8ab, causes the path of the reflected beam R to change with changes in the OSU position. The changes in the path of the reflected beam R are preserved by the mirrors 24 and 26. In this way, the path of the beam R that is reflected from the surface 26 changes. These changes correspond to the changes of the OSU. In this way, the beam R reflected by the mirror 26 can be scanned over the eye E to the required locations where refractive surgery is carried out by the beam R.

To achieve the required scan range for the beam R reflected from the mirror 26 to scan the eye E of a patient P, the optical path between the scanning device 1 and the eye E is arranged such that it is substantially one metre or more. That is to say, the distance travelled by the beam R from the scanning device 1 to the mirror 24, from the mirror 24 to the mirror 26 and from the mirror 26 to the eye E is substantially one metre or more. It is to be understood that by "substantially one

metre or more" it is meant that distances of slightly less than one metre, as well as distances of one metre or more, are suitable. This distance enables the refractive laser surgery apparatus 20, employing the OSU, to scan the range required to perform surgery on the eye E. The refractive surgery laser apparatus 20, hereinbefore described, provides an advantage in processing a material, like corneal tissue of the eye, that may move or may not be exactly the same distance from the laser system each time that the laser 22 is operated to emit a beam I. In that regard, in the OSU, employing a piezoelectrically driven actuator 10, the scan angle, i.e. the angle through which the beam R passes to scan the eye E from one extremity to the other, is much smaller than in prior art systems. Therefore, vertical movements or misalignments of the eye E during surgery will have a much smaller adverse effect on the surgical result compared to prior art galvanometric scanning systems.

Whilst the scanning device of the present invention has been exemplified by its use in a refractive surgery laser system, it may be used in other laser apparatus in which a material is processed by a laser beam.

Modifications and variations such as would be apparent to a skilled addressee are deemed to be within the scope of the present invention.

Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

Dated this Twenty Eighth day of June 2002.

CLVR Pty Ltd

Wray & Associates
Perth, Western Australia
Patent Attorneys for the Applicant(s)

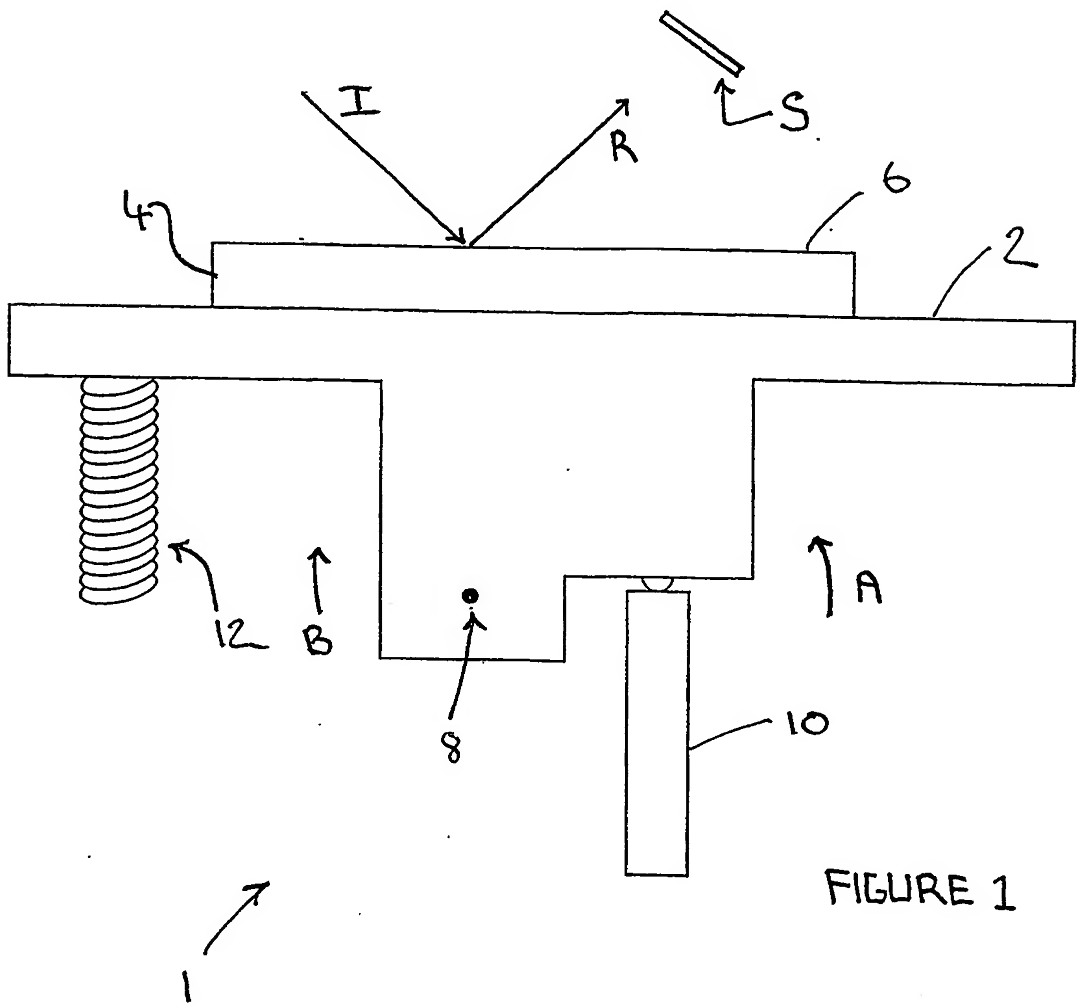

FIGURE 1

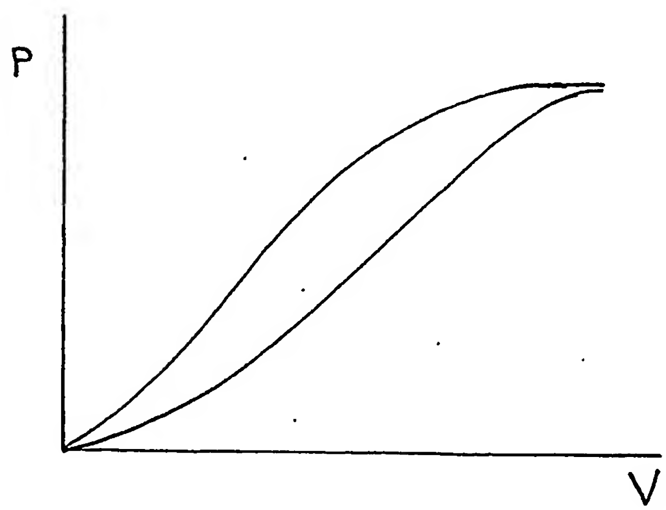

FIGURE 2

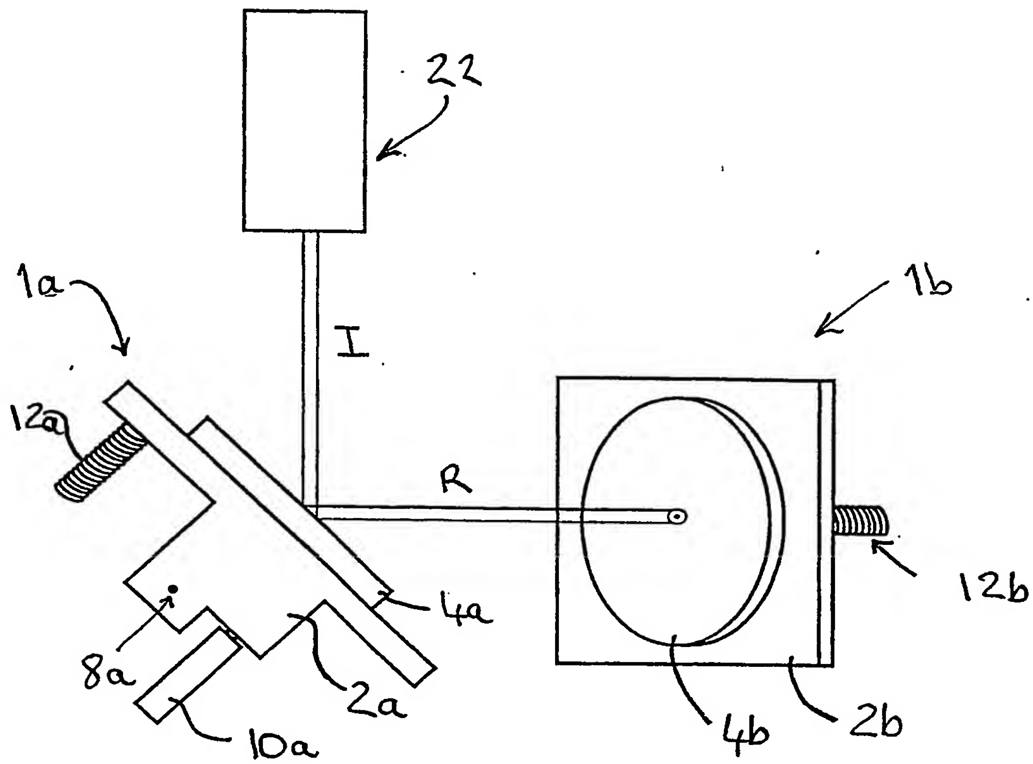

FIGURE 3

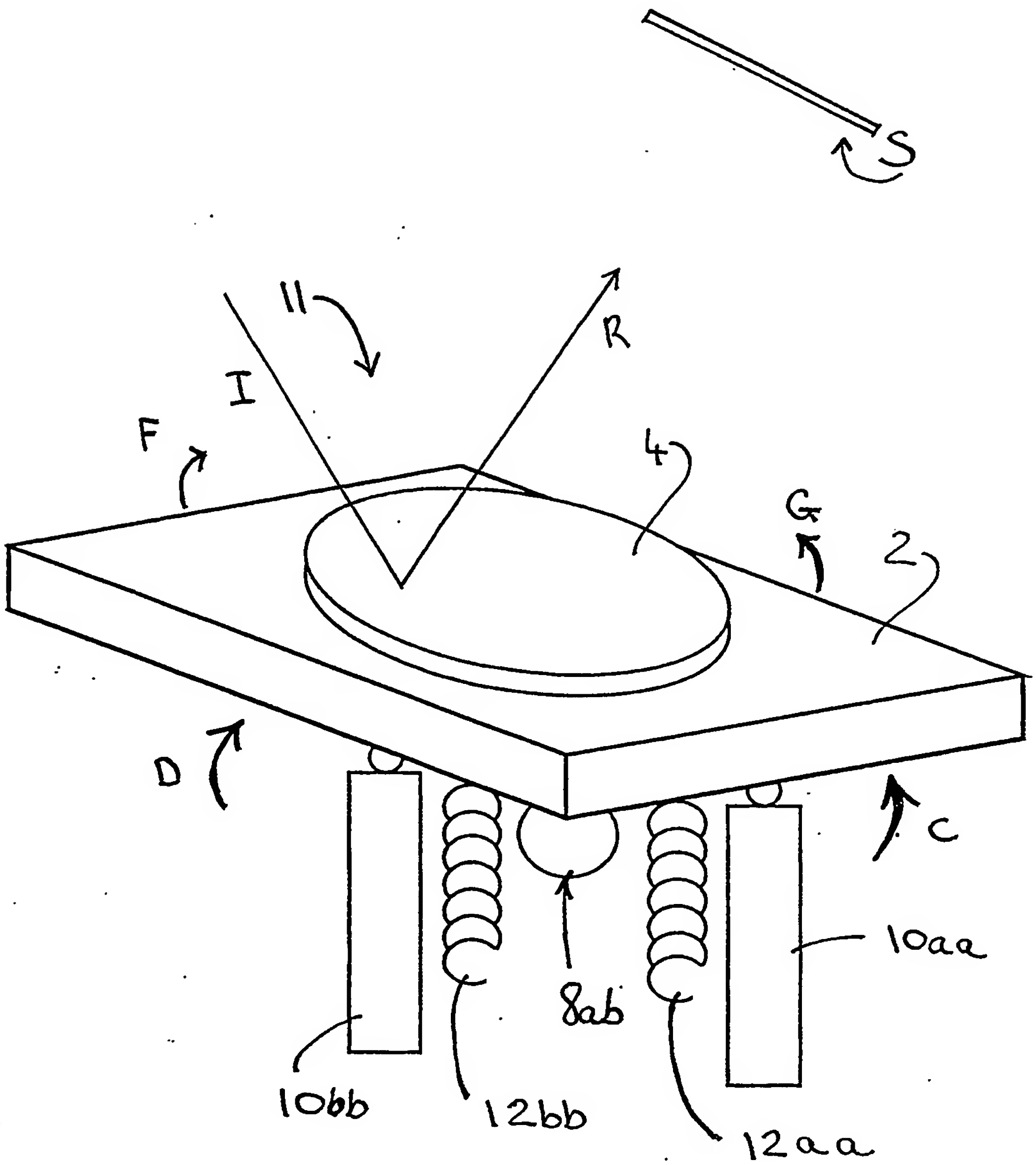

FIGURE 4

3

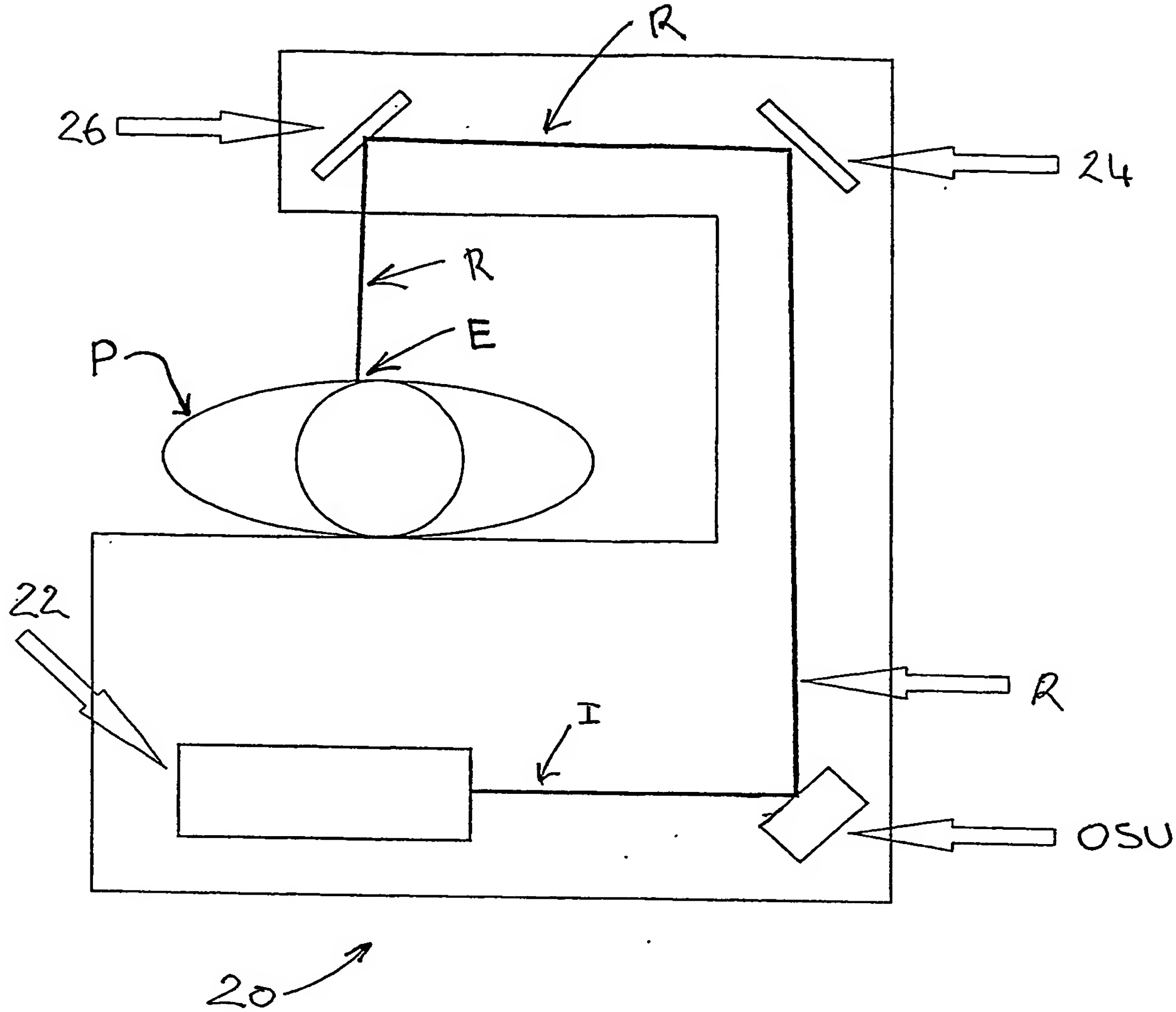

FIGURE 5